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METHODS OF REDUCING HEAT LOSS FROM SINGLE FAMILY DWELLINGS

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THIS PAPER IS A STUDY OF TWO METHODS OF REDUCING THE WINTER HEAT LOSS FROM WOOD FRAME, SINGLE FAMILY DWELLINGS. THE FIRST METHOD INVOLVES CALCULATIONS TO DETERMINE THE THERMAL VALUES OF THE SKIN COMPONENTS OF TEST BUILDINGS. THIS ANALYSIS REVEALS THE SKIN COMPONENTS MOST IN NEED OF ADDITIONAL THERMAL RESISTANCE. ONCE THIS ADDITIONAL RESISTANCE HAS BEEN INCORPORATED, A FURTHER ANALYSIS INDICATES THE MAGNITUDE OF REDUCTION OF HEAT LOSS THAT HAS BEEN ACHIEVED.

THE SECOND METHOD EMPLOYED TO REDUCE HEAT LOSS INVOLVES A REARRANGEMENT OF THE TRADITIONAL LOCATIONS OF ROOMS WITHIN THE BUILDING ENVELOPE OF THE SINGLE FAMILY DWELLING. THE INTENT OF THIS REARRANGEMENT IS TO LOCATE ROOMS WITHIN THE ENVELOPE WHERE THEY ARE MOST LIKELY TO FUNCTION EFFECTIVELY IN RELATION TO ENVIRONMENTAL CONDITIONS. BY CONTRASTING TRADITIONAL ROOM LOCATIONS WITH THESE ALTERNATE LOCATIONS, THE MAGNITUDE OF HEAT LOSS SAVINGS TO BE ACHIEVED CAN BE CALCULATED.

ONCE THESE TWO METHODS HAVE BEEN INVESTIGATED, AND THEIR MERITS ASSESSED, AN EXPERIMENTAL HOUSE, SPECIFICALLY DESIGNED TO TAKE ADVANTAGE OF THE INFORMATION GATHERED IN THE FIRST TWO SECTIONS OF THE PAPER, IS INTRODUCED. BY CALCULATING THE RATE OF HEAT LOSS FROM THIS EXPERIMENTAL HOUSE, AN INDICATION OF THE OVERALL EFFECTIVENESS OF THE METHODS EMPLOYED TO REDUCE HEAT LOSS MAY BE SEEN.

AUTHOR'S NOTE

WHEN THIS THESIS WAS BEGUN IN THE FALL OF 1973, THE IMPERIAL SYSTEM OF MEASUREMENT WAS STILL IN COMMON USAGE IN CANADA. CLIMATOLOGICAL DATA, ENGINEERING COMPUTATIONS, BUILDING DIMENSIONS, AND ARCHITECTURAL SCALES WERE ALL BASED ON IMPERIAL UNITS. THE TIMETABLE FOR METRIC CONVERSION HAD BEEN ESTABLISHED AT THIS TIME, AND IT WAS QUITE EVIDENT THAT I WAS GOING TO COMPLETE THE PAPER JUST AS THE RECORDING OF AIR TEMPERATURES WAS BEING CHANGED FROM FAHRENHEIT TO CELSIUS. THEREFORE, I CONSIDERED DOING THIS STUDY IN THE METRIC SYSTEM. THERE WERE, HOWEVER, TWO IMPORTANT CONSIDERATIONS THAT INDICATED OTHERWISE. FIRST, THE DATA THAT I NEEDED WAS ALL RECORDED IN THE IMPERIAL SYSTEM, AND WOULD HAVE TO BE CONVERTED. SECOND, INDIVIDUALS READING THE THESIS SHORTLY AFTER ITS COMPLETION WOULD BE UNFAMILIAR WITH THE METRIC SYSTEM, AND WOULD NOT FULLY COMPREHEND THE DATA PRESENTED. THEREFORE, ALL THE CALCULATIONS IN THIS STUDY ARE DONE IN THE IMPERIAL SYSTEM. MY APOLOGIES TO THE NEW GENERATION.

I DO NOT MEAN TO SAY THAT THE INFORMATION IN THIS PAPER IS OBSOLETE OR IRRELEVENT. BECAUSE IT IS A COMPARATIVE STUDY, THE MOST TELLING FIGURES ARE PERCENTAGE REDUCTIONS IN HEAT LOSS, AND THESE ARE INDEPENDENT OF ANY PARTICULAR SYSTEM OF MEASUREMENT. THE ENGINEERING CALCULATIONS ARE A MEANS TO AN END, AND THAT END IS THE SAME WHETHER THE CALCULATIONS ARE DONE IN THE IMPERIAL SYSTEM OR THE METRIC SYSTEM.

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SECTION B : DATA

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TWO STOREY	136	142	158
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FIG. 1

SECTION B, THE DATA, IS SHOWN HERE AS A MATRIX CONSISTING OF ALL THE MAJOR VARIABLES PRESENTED IN THIS THESIS. THE HORIZONTAL GRID IS A LIST OF THE HOUSE TYPES STUDIED, AND THE VERTICAL GRID IS THE TRANSFORMATIONS THROUGH WHICH THE HOUSE TYPES PASS. EACH HOUSE TYPE, BEGINNING WITH THE BUNGALOW, IS EXAMINED IN ALL OF ITS VERSIONS, FROM INITIAL TO MODIFIED, BEFORE THE NEXT TYPE IS INTRODUCED.

THE WORD 'INITIAL' IN THE MATRIX REFERS TO THE HOUSES AT THE BEGINNING OF THE STUDY, BEFORE EITHER METHOD OF REDUCING HEAT LOSS HAS BEEN APPLIED. THE INITIAL HOUSES ARE THE BASE DATA. THE REVISED HOUSES ARE A RESULT OF THE APPLICATION OF THE FIRST METHOD OF REDUCING HEAT LOSS, WHICH IS TO INCREASE THE THERMAL VALUES OF PARTICULAR COMPONENTS OF THE SKIN. THE MODIFIED HOUSES HAVE BEEN EXPOSED TO THE SECOND METHOD OF REDUCING HEAT LOSS, WHICH INVOLVES A REARRANGEMENT OF ROOMS WITHIN THE BUILDING ENVELOPE.

THE NUMBERS AT NODAL POINTS WITHIN THE MATRIX ARE PAGE NUMBERS ON WHICH PERTINENT DATA MAY BE FOUND. FOR EXAMPLE, DATA PERTAINING TO THE REVISED SPLIT LEVEL HOUSE IS ON PAGE 104.

SECTION A

METHODOLOGY

TO FULLY COMPREHEND THE ANALYSES INVOLVED IN THIS STUDY, THE READER MUST HAVE SOME UNDERSTANDING OF THE NATURE OF HEAT LOSS FROM A BUILDING. HEAT FLOWS FROM WARMER AREAS TO COOLER AREAS. THEREFORE, HEAT LOSS OCCURS AT THE SKIN OF A BUILDING WHEN THE OUTSIDE AIR TEMPERATURE IS LOWER THAN THE INSIDE AIR TEMPERATURE. THE ABILITY OF A COMPONENT OF THE SKIN TO RESIST THIS FLOW OF HEAT IS THE RESISTANCE VALUE, OR R-VALUE, OF THAT COMPONENT. THE R-VALUE OF A WALL OR ROOF IS THE SUMMATION OF THE R-VALUES OF THE MATERIALS MAKING UP THAT WALL OR ROOF. THE GREATER THE R-VALUE, THE GREATER THE THERMAL RESISTANCE OF THE ASSEMBLY.

OTHER FACTORS INFLUENCING THE RATE OF HEAT LOSS FROM A BUILDING INCLUDE THE SPEED AND DIRECTION OF THE WIND, THE NUMBER OF UNPROTECTED OPENINGS IN THE SKIN WHICH ALLOW FOR INFILTRATION, THE AREA OF WALL EXPOSED TO THE ELEMENTS, AND THE TEMPERATURE DIFFERENCE THROUGH THE WALL FROM INSIDE TO OUT. THE FORMULA U X A X ΔT YIELDS A RATE OF HEAT LOSS THROUGH A GIVEN WALL, MEASURED IN BRITISH THERMAL UNITS[1] PER HOUR (BTU/HR.), WHERE U, THE RECIPROCAL OF R, IS THE

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1. THE AMOUNT OF HEAT REQUIRED TO RAISE THE TEMPERATURE OF ONE POUND OF WATER ONE DEGREE FAHRENHEIT.

RATE OF HEAT LOSS PER SQUARE FOOT OF WALL PER DEGREE FAHRENHEIT TEMPERATURE DIFFERENCE, A IS THE AREA OF THE WALL, AND ΔT THE DIFFERENCE IN TEMPERATURE THROUGH THE WALL. THE ONLY WAYS OF DECREASING THE RATE OF HEAT LOSS THROUGH A WALL ARE TO INCREASE THE THERMAL RESISTANCE OF THE WALL, DECREASE THE AREA OF THE WALL EXPOSED TO THE ELEMENTS, OR REDUCE THE TEMPERATURE DIFFERENCE THROUGH THE WALL.

THE VELOCITY AND DIRECTION OF THE WIND AFFECT THE U-VALUE OF THE WALL. A MICROSCOPIC LAYER OF STILL AIR, CLINGING TO THE WALL THROUGH FRICTION, HAS A SPECIFIC THERMAL VALUE, SINCE IT TENDS TO ISOLATE THE OUTSIDE SURFACE OF THE WALL FROM THE AMBIENT AIR. IF THE WIND IS BLOWING, IT REMOVES THIS LAYER OF AIR, OR PART OF IT, AND THEREBY LESSENS THE THERMAL VALUE OF THE WALL.

THE INFILTRATION OF COLD AIR INTO THE BUILDING CONTRIBUTES TO HEAT LOSS BY DISPLACING WARM INSIDE AIR. SINCE ACTUAL RATES OF INFILTRATION ARE SELDOM EQUAL TO RECOMMENDED RATES OF VENTILATION, THE RECOMMENDED VENTILATION RATE OF 75 CUBIC FEET PER MINUTE[2] OF FRESH OUTSIDE AIR WILL BE USED IN THIS STUDY.

THERE ARE ADDITIONAL CRITERIA THAT ARE SOMETIMES USED IN CALCULATING RATES OF HEAT LOSS FROM BUILDINGS. THESE ARE ESSENTIALLY SOURCES OF HEAT GAIN, AND INCLUDE SOLAR GAIN,

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2. CARRIER SYSTEM DESIGN MANUAL, CARRIER CORPORATION 1972.

AND GAINS FROM PEOPLE, LIGHTS, MOTORS, AND APPLIANCES. ALTHOUGH THESE HEAT GAINS AFFECT THE AMOUNT OF HEATING REQUIRED IN A BUILDING, THEY HAVE NO DIRECT AFFECT UPON THE RATES OF HEAT LOSS THROUGH THE SKIN OF A BUILDING, AND WILL THEREFORE BE EXCLUDED FROM THIS STUDY.

S C O P E

SINCE IT IS NOT POSSIBLE WITHIN THE SCOPE OF THIS INVESTIGATION TO TEST ACTUAL HOUSE, THEORETICAL HOUSES, SUBJECT TO THEORETICAL CLIMATIC CONDITIONS, ARE USED INSTEAD. THE PLANS OF THESE THEORETICAL HOUSES HAVE BEEN SELECTED FROM THE CENTRAL MORTGAGE AND HOUSING CORPORATION'S (CMHC) BOOK OF HOUSE DESIGNS, AND ARE INTENDED TO REPRESENT TYPICAL CANADIAN SINGLE FAMILY DWELLINGS.[3] THE THREE HOUSES ARE REPRESENTATIVE OF THE THREE MAJOR HOUSE TYPES BEING BUILT IN CANADA TODAY - BUNGALOW, SPLIT LEVEL, AND TWO STOREY. ALL THREE HOUSES HAVE THREE BEDROOMS, A SINGLE WASHROOM, KITCHEN, AND COMBINED LIVING - DINING ROOMS. SOME MODIFICATIONS HAVE BEEN MADE TO THE BUILDINGS, PARTICULARLY THE TWO STOREY HOUSE, TO ENSURE THAT ALL THREE HOUSES HAVE EQUAL PLAN AREAS AND EQUAL WINDOW OPENINGS. THESE CHANGES WERE MADE TO ENSURE THAT ANY COMPARISONS STEMMING FROM AN EVALUATION OF THE THERMAL PERFORMANCES OF VARIOUS HOUSES WOULD BE VALID. CONSTRUCTION DETAILS OF THE THREE HOUSES, INCLUDING INSULATION STANDARDS USED, ARE TO BE FOUND ON PAGES 50, 52, AND 54 FOR THE BUNGALOW, 88, 90, AND 92 FOR THE SPLIT LEVEL, AND 126, 128, AND 130 FOR THE TWO STOREY HOUSE.

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3. HOUSE DESIGNS PREPARED BY CANADIAN ARCHITECTS FOR CENTRAL MORTGAGE AND HOUSING CORPORATION

CLIMATIC CONDITIONS USED IN THIS STUDY ARE THOSE OF WINNIPEG, MANITOBA. THE OUTSIDE WINTER DESIGN TEMPERATURE USED IS -30° F.,[4] AND THE WIND IS ASSUMED TO BE COMING OUT OF THE NORTH-WEST AT 15 MPH.[5] OTHER DATA PERTINENT TO THE CALCULATIONS OF HEAT LOSS FROM BUILDINGS MAY BE FOUND IN THE APPENDIX.

THE FIRST METHOD OF REDUCING HEAT LOSS IS TO INCREASE THE THERMAL VALUE OF THE SKINS OF THE CMHC TEST BUILDING, ALL OF WHICH ARE OF WOOD FRAME CONSTRUCTION. ON THIS CONTINENT, WOOD HAS ALWAYS BEEN ABUNDANT, AND THEREFORE INEXPENSIVE. IT IS LIGHT, STRONG, EASILY CUT, AND SIMPLE TO ERECT. WITH ALL OF THESE FACTORS IN ITS FAVOUR, WOOD FRAME CONSTRUCTION HAS BECOME THE STANDARD METHOD OF HOUSE BUILDING THROUGHOUT NORTH AMERICA. HOWEVER, BECAUSE OF THE WIDE VARIETY OF CLIMATIC CONDITIONS TO BE FOUND FROM ONE END OF THE CONTINENT TO THE OTHER, VARIATIONS AND ADAPTATIONS TO THE METHOD HAVE EVOLVED. IN A CLIMATIC ZONE THAT IS COLD FOR A GOOD PART OF THE YEAR, SUCH AS WESTERN CANADA'S, THE ADAPTATIONS INCLUDE INSULATION IN THE WALLS, AND CEILING, A VAPOUR BARRIER, DOUBLE GLAZED WINDOWS, AND FOUNDATIONS EXTENDING INTO THE GROUND BELOW THE DEPTH OF FROST PENETRATION. HOWEVER, ONLY THOSE VARIATIONS NECESSARY TO ALLOW THE INDIVIDUAL TO HEAT HIS HOME ECONOM-ICALLY HAVE BEEN INCORPORATED INTO THE BUILDING TECHNIQUE. OTHER POSSIBLE VARIATIONS THAT WOULD REDUCE HEAT LOSS EVEN

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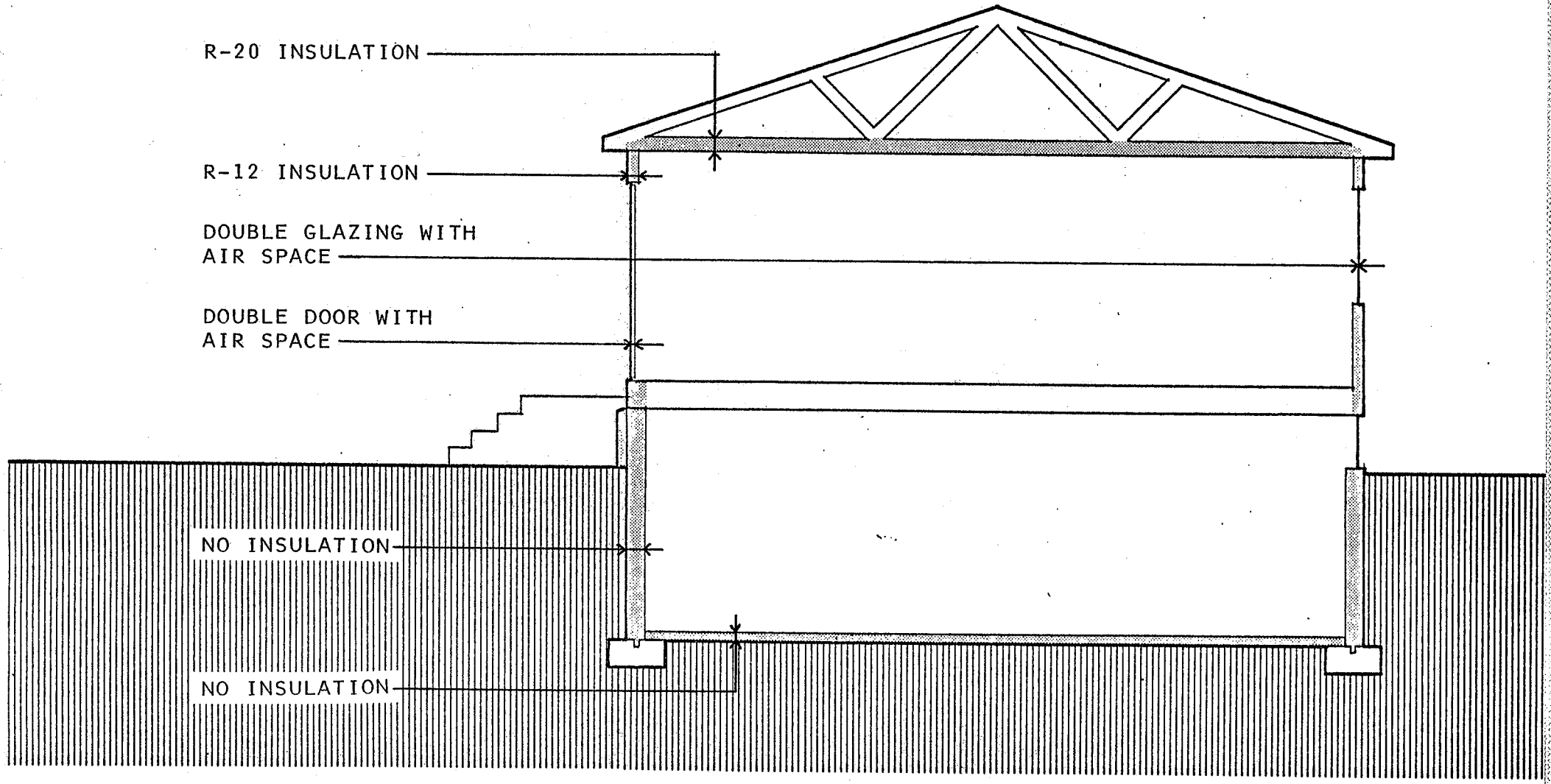


TYPICAL TRANSVERSE SECTION

SCALE : 3/16" = 1'-0"

FIG. 2

FURTHER HAVE NOT OCCURRED BECAUSE THEY WOULD INVOLVE ADDITIONAL EXPENSE TO INSTITUTE, AND ENERGY IN THE FORM OF HEATING FUELS HAS BEEN READILY AVAILABLE, AND INEXPENSIVE. IN OTHER WORDS, THE QUESTION OF WHAT THICKNESS OF INSULATION TO BE PLACED IN THE WALLS, OR HOW MANY PANES OF GLASS TO BE PLACED IN THE WINDOWS, IS RESOLVED THROUGH THE USE OF AN ECONOMIC EQUATION. THE LONG TERM COST OF HEATING THE HOUSE MUST BALANCE THE SHORT TERM COST OF INSULATING THE HOUSE. IF ONE SIDE OF THIS EQUATION, THE VALUE OF ENERGY, INCREASES, THE OTHER SIDE, THE THERMAL VALUE OF THE SKIN OF THE HOUSE, MUST INCREASE SUCH THAT THE EQUATION WILL CONTINUE TO BALANCE.

SINCE ACTUAL ENERGY COSTS ARE CHANGING VERY RAPIDLY AT THE PRESENT TIME, IT IS POINTLESS TO ATTEMPT IN THIS PAPER TO DEFINE THESE COSTS. INSTEAD, HEAT LOSS, IN BTU/HR., SHALL BE USED AS THE CONSTANT FACTOR. AT ANY GIVEN MOMENT, HEAT LOSS AND ENERGY COSTS ARE DIRECT FUNCTIONS OF ONE ANOTHER, SINCE THE ENERGY REQUIRED TO HEAT A BUILDING IS EXACTLY EQUAL TO THE ENERGY OF THE HEAT LOST FROM THE BUILDING. AT THE PRESENT TIME, THE COST OF ENERGY DICTATES THAT A HOUSE BE INSULATED AS ILLUSTRATED IN FIG. 2 . AS THE COST OF ENERGY CONTINUES TO INCREASE, FURTHER ADAPTATIONS TO THE SKIN OF THE SINGLE FAMILY DWELLING WILL OCCUR. BY CALCULATING THE PATTERN OF HEAT LOSS OCCURRING FROM THE THREE HOUSE TYPES, IT SHOULD BE POSSIBLE TO DETERMINE WHICH COMPONENT OR COMPONENTS ARE MOST IN NEED OF GREATER THERMAL RESISTANCE WHEN INCREASED ENERGY COSTS DICTATE A FURTHER ADAPTATION OF THE SKIN

OF THE SINGLE FAMILY DWELLING.

THE CALCULATIONS OF HEAT LOSS FROM THE THREE TYPICAL HOUSE TYPES MAY BE FOUND ON PAGES 60, 98 , AND 136. IN THE BUNGALOW, THE GREATEST HEAT LOSS, 32.0% OF THE TOTAL, OCCURRED AT THE FOUNDATION, AND THE LARGEST COMPONENT OF THE FOUNDATION HEAT LOSS WAS THE TWO FOOT STRIP OF CONCRETE EXTENDING ABOVE GRADE, WHICH ACCOUNTED FOR FULLY 80% OF THE TOTAL HEAT LOST BY THE FOUNDATION. THE NEXT GREATEST HEAT LOSS FROM THE BUNGALOW OCCURRED THROUGH THE WINDOWS, AND REPRESENTED 26.2% OF THE TOTAL HEAT LOSS.

IN THE SPLIT LEVEL HOUSE, THE GREATEST PERCENTAGE HEAT LOSS OCCURRED AT THE WINDOWS, AND REPRESENTED 30.0% OF THE TOTAL HEAT LOSS FROM THIS HOUSE. THE ACTUAL HEAT LOSS OF 15,594 BTU/HR. IS VERY SIMILAR TO THE HEAT LOST THROUGH THE WINDOWS OF THE BUNGALOW. THE FOUNDATION HEAT LOSS OF 10,836 BTU/HR., OR 20.8% OF THE TOTAL, IS SOMEWHAT SMALLER THAN THAT OF THE BUNGALOW. AGAIN, THOUGH, THE WINDOWS AND FOUNDATION WALLS REPRESENT THE POINTS OF GREATEST HEAT LOSS FROM THE HOUSE.

THE SAME HOLDS TRUE IN THE CASE OF THE TWO STOREY HOUSE. THE WINDOW HEAT LOSS OF 15,227 BTU/HR., OR 29.9% OF THE TOTAL, IS VERY SIMILAR TO THE VALUES CALCULATED IN THE OTHER TWO HOUSE TYPES. THE FOUNDATION LOST 11,135 BTU/HR., OR 21.9% OF THE TOTAL HEAT LOSS. THIS VALUE IS VERY SIMILAR TO THAT OF THE SPLIT LEVEL, SINCE THE TWO HOUSES HAVE ALMOST EQUAL

AMOUNTS OF FOUNDATION WALL.

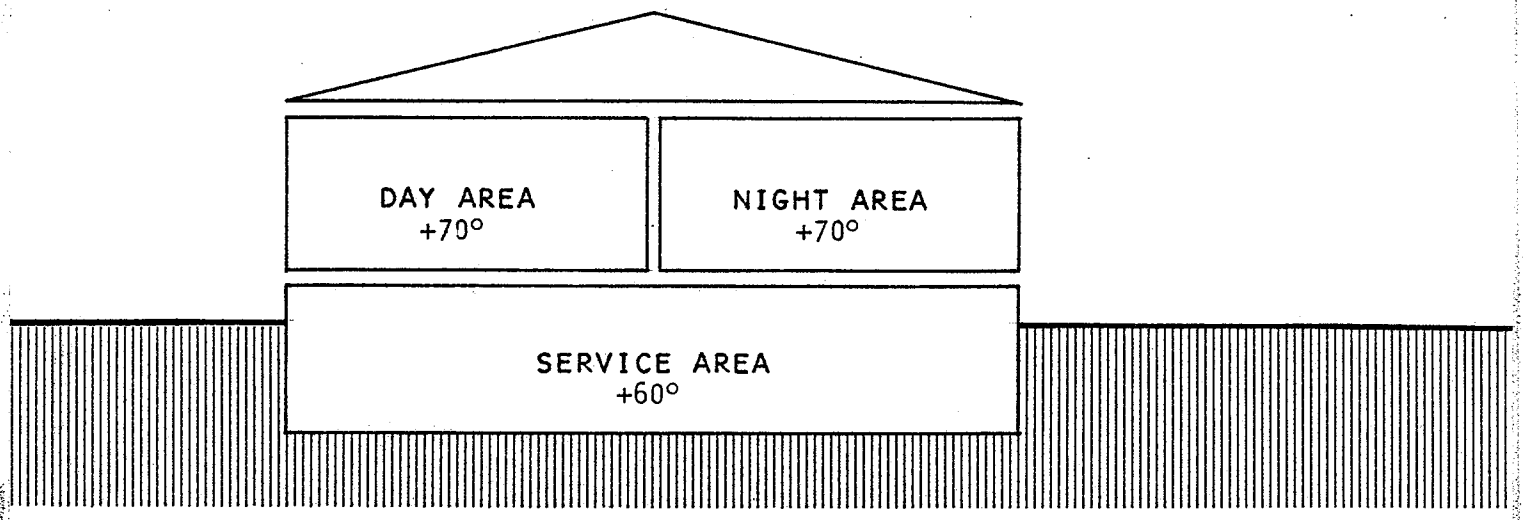
THE CONCLUSION TO BE DRAWN FROM THIS ANALYSIS IS THAT THE WINDOW AND FOUNDATION WALL COMPONENTS OF THE SKIN OF THE SINGLE FAMILY DWELLING ARE THE POINTS AT WHICH ADDITIONAL THERMAL RESISTANCE SHOULD BE APPLIED TO REDUCE HEAT LOSS. IT IS PROBABLY SAFE TO ASSUME THAT MOST HOMEOWNERS ARE AWARE THAT RELATIVELY LARGE QUANTITIES OF HEAT ARE LOST THROUGH WINDOWS, AND THAT THEY ARE WILLING TO BEAR THE COST OF THIS HEAT LOSS IN RETURN FOR THE AESTHETIC ADVANTAGES OF HAVING WINDOWS IN THEIR HOMES. ON THE OTHER HAND, IT IS PROBABLY EQUALLY SAFE TO ASSUME THAT RELATIVELY FEW HOMEOWNERS WOULD BE AWARE OF THE MAGNITUDE OF HEAT LOSS THAT IS OCCURRING THROUGH THE FOUNDATION OF THEIR HOMES, AND THAT WERE THEY AWARE OF THIS FACT, THEY WOULD BE IN A POSITION TO DECIDE WHETHER OR NOT THEY WISHED TO INSULATE THE FOUNDATION.

IN ORDER TO DETERMINE THE POTENTIAL SAVINGS THAT MAY BE REALIZED BY INCREASING THE THERMAL RESISTANCE OF THE WINDOWS AND FOUNDATION WALLS, THE THREE TYPICAL HOUSE TYPES HAVE BEEN REVISED. THE CHANGES ARE FROM DOUBLE GLAZING TO TRIPLE GLAZING IN ALL WINDOWS, AND FROM NO INSULATION TO 2" OF RIGID INSULATION ON THE OUTSIDE FACE OF THE FOUNDATION WALLS ABOVE GRADE. THE HEAT LOSS CALCULATIONS RESULTING FROM THESE CHANGES ARE TO BE FOUND ON PAGES 66, 104, AND 142.

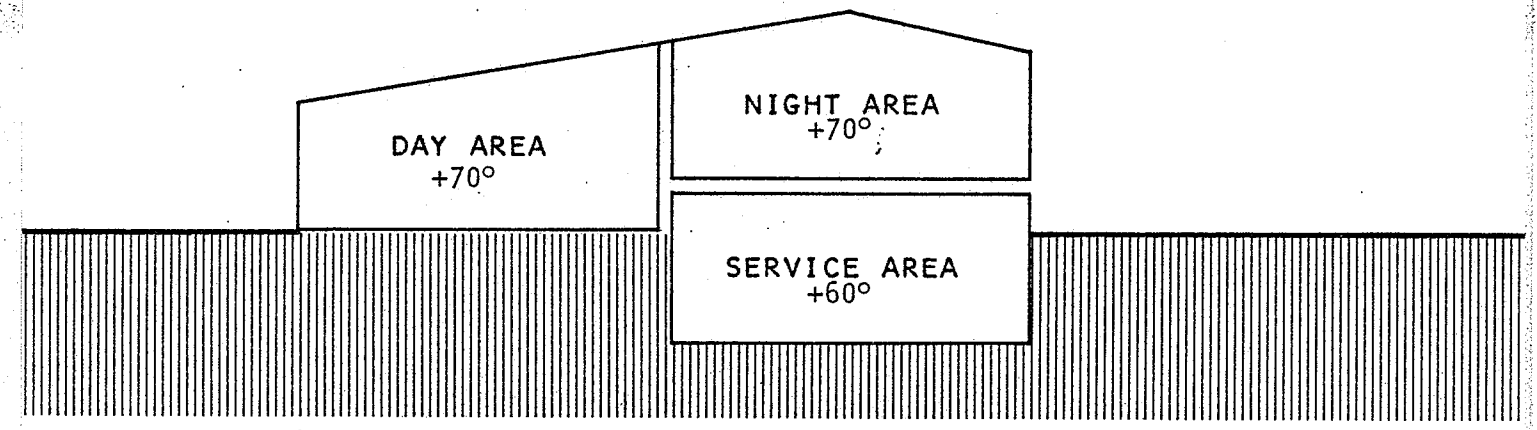
THIS POINT IN THE PAPER MARKS THE END OF THE INVESTIGATION OF THE FIRST METHOD OF REDUCING HEAT LOSS FROM WOOD FRAME, SINGLE FAMILY DWELLINGS. IT HAS BEEN ESTABLISHED THAT THE TWO POINTS OF GREATEST HEAT LOSS FROM TRADITIONALLY CONSTRUCTED HOUSES ARE THE WINDOWS AND THE FOUNDATION WALLS. WHEN THE THERMAL RESISTANCE OF THESE TWO COMPONENTS IS INCREASED AS DESCRIBED EARLIER, HEAT LOSS FROM THE HOUSE DROPS BY AN AVERAGE OF 27.7%

THE SECOND METHOD EMPLOYED TO REDUCE HEAT LOSS INVOLVES A REARRANGEMENT OF THE TRADITIONAL LOCATIONS OF ROOMS WITHIN THE BUILDING ENVELOPE. UNLIKE THE PREVIOUS METHOD EXPLORED, THIS INVESTIGATION HAS LITTLE RELEVANCE TO THE OWNER OF AN EXISTING HOUSE.

THE "PERFECT" ENERGY CONSERVING HOUSE IN TERMS OF HEAT LOSS WOULD BE LOCATED ENTIRELY BELOW GRADE, SO THAT ITS SKIN WAS COMPLETELY SURROUNDED BY A BLANKET OF EARTH PROTECTING IT FROM AIR AT -30° F., FOR ALTHOUGH THE GROUND IN WINNIPEG IS FROZEN FOR APPROXIMATELY SEVEN MONTHS OF THE YEAR, THE TEMPERATURE OF THIS FROZEN SOIL REMAINS CONSIDERABLY HIGHER THAN THAT OF THE OUTSIDE AIR . THEREFORE, IN A HOUSE LOCATED BELOW GRADE, THE TEMPERATURE DIFFERENCE FROM INSIDE TO OUT WOULD BE MUCH LOWER, AS WOULD THE HEAT LOSS FROM THE HOUSE. IT IS THE OPINION OF THE AUTHOR, HOWEVER, THAT A HOUSE



B U N G A L O W



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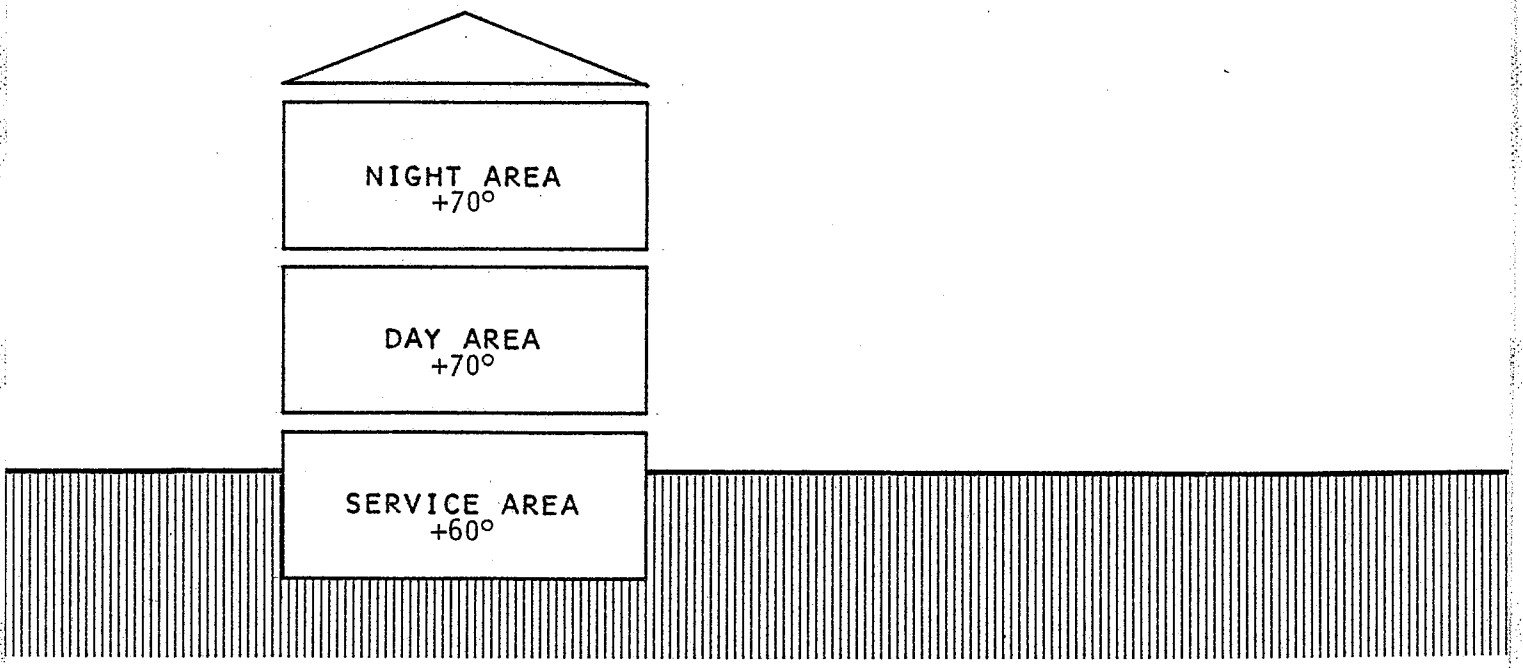

T W O S T O R E Y

FIG. 3